A gradient-enhanced continuum damage model for fibre-reinforced materials

Polindara C. [1], Waffenschmidt T.[2], Menzel A.[2], Blanco S.[1], Goicolea J.[1]

[1] Universidad Politécnica de Madrid, Spain, cpolindara@mecanica.upm.es
[2] Technische Universität Dortmund, Germany

Introduction

A non-local gradient-enhanced continuum damage model for fibre-reinforced materials is presented. The model follows the concepts discussed in [1] where the local free energy function is enhanced with a gradient term of a non-local damage variable. The coupled system of equations, i.e. the balance of momentum and the balance of the non-local damage field, is dicretized by means of the Finite Element Method and implemented in the comercial code Abaqus via the user subroutine UEL. Different BVP's are studied and the results show that the proposed finite element implementation is suitable for the study of typical problems in the biomechanics of soft tissues.

Materials and methods

The presented model aims to reproduce the degradation of the mechanical properties in a fibre-reinforced material with special focus on the GOH material model [2]. In this contribution only the damage of the fibres is taken into account while the neo-Hookean matrix remains elastic. Following the ideas discussed in [1] two damage variables κ and φ , namely the local and non-local, are defined, and then the fibres local free energy function is modified as:

$$\Psi_{fib} = f(\kappa)\Psi^{elas}_{fib} + \frac{c_d}{2}\nabla^2(\varphi) + \frac{\beta_d}{2}(\varphi-\gamma_d\kappa)^2$$

where $f(\kappa)\in[0,1]$ is a damage function that weights the elastic (undamaged) fibres local free energy function. The second r.h.s. term in the equation is the contribution of the non-local damage variable that regularises the model, while the third one is a penalty term that enforces the restriction $\kappa-\varphi=0$.

The balance equations (momentum and non-local damage) are discretized following the Galerkin method and implemented in Abaqus via the user subroutine UEL where Q1P1 and Q2P1 hexahedral elements are defined.

Results and discussion

Three different BVP's are studied in order to evaluate the properties of the resulting finite element implementation: a homogeneus deformation case, a plate with a hole, and a ring under internal pressure. Load-displacement and stress-streching curves for every BVP haven been retrieved. These curves are contained within two limiting cases, namely a purely elastic neo-Hookean or a purely elastic fibre-reinforced response. These curves show that as damage evolves the response of the structure deviates from the purely elastic fibre-reinforced behaviour and reaches, in some cases when damage is total, a purely neohookean one.

Different discretizations have been tested for the plate with a hole. For these cases the resulting load-displacement curves have not shown major discrepancies, i. e. no mesh-dependence is obtained, which is a result of the implicit regularisation that entails the inclusion of the gradient term in the local free energy function. This is one of the key benefits from the proposed model.

A ring under internal pressure is also studied. This is a typical example of a problem that arises in the biomechanics of arteries. Experimental data from [3] have been used and the results show that the proposed model is able to reproduce the fibres degradation within the phisiological range.

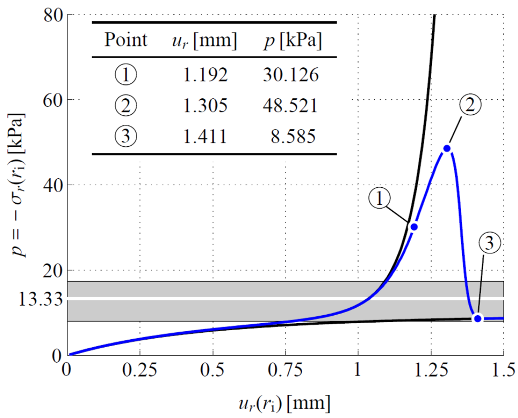

Fig. 1: Radial stress of a ring under internal pressure.

Conclusion

The presented model and its correspondent finite element implementation is suitable for the study of typical problems in the biomechanics of soft tissues such as arteries.

References

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